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Function Analysis of the Single-Shell Tank Waste Retrieval Manipulator System

J. V. Draper

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Environmental Restoration and Waste Management Program

FUNCTION ANALYSIS OF THE SINGLE-SHELL TANK WASTE RETRIEVAL MANIPULATOR SYSTEM

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ABSTRACT

This document lists the functions likely to be performed by each proposed component of the Tank Waste Retrieval Manipulator System (TWRMS) and the user functions that must be performed to operate each component. While the information contained in this document is tentative because the systems are still evolving, it provides a foundation for task analysis and control room design efforts. These efforts will support the design of a test-bed control room in the near future and an operational control room later. The information in this document is based on specifications published for the TWRMS.

1. INTRODUCTION

This document lists the functions likely to be performed by each proposed component of the Tank Waste Retrieval Manipulator System (TWRMS) and the user functions that must be performed to operate each component. While the information contained in this document is tentative because the systems are still evolving, it provides a foundation for task analysis and control room design efforts. These efforts will support the design of a test-bed control room in the near future and an operational control room later. The information in this document is based on specifications published for the TWRMS.[1]

Control room design must proceed systematically if it is to be effective. One approach is to follow three phases: (1) function analysis, (2) task analysis, and (3) design. In the function analysis phase, the control requirements are identified and evaluated from an ergonomic perspective. This requires listing all functions that must be performed from the control room, organizing functions into related groups, determining crew size, and allocating functions to crew members. The outcome of this phase of the design is a function plan for the control room. The function plan identifies how many people will be needed to operate the system and what action each operator must take. Because the TWRMS is an emerging system, this analysis must be reviewed prior to developing final control room concepts to ensure that the conclusions contained within it remain applicable.

The TWRMS will comprise systems capable of teleoperation and autonomous operations. The crew will control the system using supervisory control,[2] a control scheme in which the user's role shifts from continuous manual control to symbolic interaction, depending on the circumstances. In other words, the user's contribution will range from controlling every movement of the machine by directly controlling servomotor operation to entering task-level commands. Specifically, during supervisory control of a teleoperator a user carries out some varying mix of five tasks: (1) programming—storing a behavioral repertoire via symbols, including words; (2) teaching—storing a behavioral repertoire by stepping through examples; (3) controlling—exercising continuous manual control; (4) commanding—control via manipulating symbols to trigger behavioral repertoires; and (5) monitoring—observing the machine perform commands and switching to another task as required.

A control room for the TWRMS must include workstations that can support all five user tasks during waste tank remediation campaigns. This document provides supporting information for the design of such workstations by listing the user functions that may be required; it will also serve as a foundation for future task analysis and workstation design efforts.

2. TWRMS FUNCTION LIST

The first step in function analysis is to list the subsystems which must be operated from the control room, the functions that each will perform, and what users must do to operate them. The outcome of this part of the analysis will be an exhaustive list of the actions operators must take. In a system like the TWRMS this is made difficult by the fact that it is a developmental system, and subsystem designs are not complete. In this context, the function list must anticipate the requirements of the final system and it is wise to err towards conservatism, in this case, to assume that all functions under consideration will be included.

This section lists the equipment required to perform waste retrieval operations. Each subsection identifies a subsystem, lists subsystem functions by task phase, and lists user functions necessary to operate the equipment. For some subsystem functions, more than one user function may be identified. For example, monitoring manipulator force sensors has three user functions: (1) monitor force sensors haptically (by touch), (2) monitor force sensor aurally (by sound), and (3) monitor force sensors visually. These cases require further detailed design definition before the appropriate user function may be identified. It is unlikely that more than one user function will be required in these cases; however a complete set is included.

2.1 RETRIEVAL MANIPULATOR

The TWRMS is the telerobotic arm that will be used for positioning waste retrieval devices (end effectors) within the tank. It may be either robotically operated or teleoperated.

2.1.1 System Functions

System functions will vary depending upon the type of operation the TWRMS is conducting at any particular time. This may include (1) deployment–inserting the TWRMS into a single-shell tank or removing it; (2) gross-positioning manipulator operations–using the gross-positioning system to place the fine-positioning system within a work volume; (3) fine-positioning manipulator operations–using the fine-positioning manipulator for dexterous operations; (4) end-effector operations–exercising control over end effectors. Some system management functions will also be necessary at all times.

2.1.1.1 Deployment

1. Teleoperated deployment
2. Robotic deployment

2.1.1.2 Gross-positioning manipulator operations

1. Teleoperated movement in X, Y, Z, and ϕ
2. Assisted teleoperation
3. Integrated manipulator control

4. Force/torque feedback
5. Position feedback
6. Audio feedback
7. Sensor-based obstacle avoidance
8. Teach playback, including teach, step-through playback, semiautomatic playback, and supervised playback

2.1.1.3 Fine-positioning manipulator operations

1. Teleoperated movement in X, Y, Z, and ϕ
2. Assisted teleoperation
3. Integrated manipulator control
4. Force/torque feedback
5. Position feedback
6. Audio feedback
7. Sensor-based obstacle avoidance
8. Teach playback, including teach, step-through playback, semiautomatic playback, and supervised playback

2.1.1.4 End-effector operations

1. End-effector control
2. Automated end-effector changeout

2.1.1.5 System management

1. Start system
2. Normal shutdown
3. Provide emergency shutdown
4. Watchdog alarm/shutdown
5. System restart
6. Operations log
7. Diagnostics

2.1.2 User Functions

1. During robotic deployment
2. Start system.
3. Initiate robotic deployment sequence.
4. Monitor deployment.
5. Manually shut down system–emergency.
6. Shut down system–normal.
7. Restart system.
8. Maintain operations log.
9. Monitor system status.

2.1.2.1 During teleoperated deployment

1. Start system.
2. Manually maneuver manipulator through opening.
3. Detect watchdog action.
4. Monitor deployment.
5. Manually shut down system–emergency.
6. Shut down system–normal.
7. Restart system.
8. Maintain operations log.
9. Monitor system status.

2.1.2.2 During manipulator operations

1. Start system.
2. Detect watchdog action.
3. Visually monitor end-effector trajectories on video.
4. Visually monitor manipulator position on world model.
5. Adjust system parameters (force feedback gain, indexing, and motion gain).
6. Monitor manipulator forces (visually via displays, haptically via force reflection, or aurally via speakers).
7. Aurally monitor remote sounds.
8. Monitor collision avoidance system.
9. Manually control end effector using position control.
10. Manually control end effector using rate control.
11. Engage assisted teleoperation.
12. Engage integrated manipulator control.
13. Engage sensor-based obstacle avoidance.
14. Engage teaching.
15. Manually make teaching inputs.
16. Engage step-through playback.
17. Engage semiautomatic playback.
18. Engage automatic playback.
19. Visually monitor playback on video.
20. Visually monitor playback on world model.
21. Manually shut down system–emergency.
22. Shut down system–normal.
23. Restart system.
24. Monitor system status.
25. Maintain operations log.

2.1.2.4 During end effector operations

1. Engage end effector.
2. Detect watchdog action.
3. Visually monitor end-effector operations on video.
4. Initiate automated end-effector changeout.
5. Visually monitor automated end-effector changeout on video.
6. Visually monitor automated end-effector changeout on world model.

2.2 END EFFECTORS

2.2.1 Soft Waste Dislodging Equipment

The soft waste dislodging equipment will be used to remove soft waste from the tank. Soft waste may range in consistency from liquid to gelatinous. The soft waste dislodging equipment will comprise an end effector attached to the TWRMS.

2.2.1.1 System functions

1. Loosen waste.
2. Capture waste.
3. Transfer waste to conveyance system.
4. Provide sensor data to control system.
5. Provide emergency shutdown.

2.2.1.2 User functions

1. Engage soft waste end effector.
2. Manually control TWRMS (gross positioning).
3. Manually control TWRMS (fine positioning).
4. Monitor end-effector sensor data (visually, haptically, or aurally).
5. Supervise robotic TWRMS and end effector operations.
6. Manually shut down system–emergency.

2.2.2 Hard Waste Dislodging Equipment

Hard waste dislodging equipment will be used to break up and capture solidified waste. It will comprise an end effector attached to the TWRMS.

2.2.2.1 System functions

1. Break up hard waste.
2. Capture waste fragments.
3. Transfer waste fragments to conveyance system.
4. Provide sensor data to control system.
5. Provide emergency shutdown.

2.2.2.2 User functions

1. Engage hard waste dislodging end effector.
2. Manually control TWRMS (gross positioning).
3. Manually control TWRMS (fine positioning).
4. Monitor end-effector sensor data (visually, haptically, or aurally).
5. Supervise robotic TWRMS and end-effector operations.
6. Manually shut down system–emergency.

2.2.3 Hard Waste Rubblizing Equipment

The hard waste rubblizing equipment will be used to break up solidified waste that is too hard to be handled by the hard waste dislodging equipment. It will comprise an end effector attached to the TWRMS.

2.2.3.1 System functions

1. Break up hard waste.
2. Provide sensor data to control system.
3. Provide emergency shutdown.

2.2.3.2 User functions

1. Engage rubblizing end effector.
2. Manually control TWRMS (gross positioning).
3. Manually control TWRMS (fine positioning).
4. Monitor end effector sensor data (visually, haptically, or aurally).
5. Supervise robotic TWRMS and end-effector operations.
6. Manually shut down system–emergency.

2.2.4 Post-Rubblizing Equipment

Post-rubblizing equipment will be used to capture waste fragmented by the waste rubblizing equipment. It will comprise an end effector attached to the TWRMS.

2.2.4.1 System functions

1. Break up rubblized hard waste.
2. Capture waste fragments.
3. Transfer waste fragments to conveyance system.
4. Provide sensor data to control system.
5. Provide emergency shutdown.

2.2.4.2 User functions

1. Engage post-rubblizing end effector.
2. Manually control TWRMS (gross positioning).
3. Manually control TWRMS (fine positioning).
4. Monitor end-effector sensor data (visually, haptically, or aurally).
5. Supervise robotic TWRMS and end-effector operations.
6. Manually shut down system–emergency.

2.2.5 In-Tank Cleaning Equipment

In-tank cleaning equipment will be used at the end of a waste removal campaign to capture residual waste from the bottom and sides of the tank. It will comprise an end effector attached to the TWRMS.

2.2.5.1 System functions

1. Remove residual waste from tank wall or in-tank hardware (ITH).
2. Capture residual waste.
3. Transfer waste to waste conveyance system.
4. Provide sensor data to control system.
5. Provide emergency shutdown.

2.2.5.2 User functions

1. Engage cleaning end effector.
2. Manually control TWRMS (gross positioning).
3. Manually control TWRMS (fine positioning).
4. Monitor end-effector sensor data (visually, haptically, or aurally).
5. Supervise robotic TWRMS and end-effector operations.
6. Manually shut down system–emergency.

2.2.6 Large Cutter End Effector

The large cutter end effector will be used to cut large pieces of riser pipes and other ITH into small pieces that can be handled by the gripper end effector and hardware conveyance system. It will comprise an end effector attached to the TWRMS.

2.2.6.1 System functions

1. Cut ITH.
2. Support ITH during cutting.
3. Provide sensor data to control system.
4. Provide emergency shutdown.

2.2.6.2 User functions

1. Engage large cutter end effector
2. Manually control TWRMS (gross positioning)
3. Manually control TWRMS (fine positioning)
4. Monitor end-effector sensor data (visually, haptically, or aurally)
5. Supervise robotic TWRMS and end-effector operations
6. Manually shut down system–emergency

2.2.7 Small Cutter End Effector

The small cutter end effector will be used to cut small pieces of riser pipes and ITH into small pieces that can be handled by the gripper end effector and hardware conveyance system. It will comprise an end effector attached to the TWRMS.

2.2.7.1 System functions

1. Shear ITH.
2. Provide sensor data to control system.
3. Provide emergency shutdown.

2.2.7.2 User functions

1. Engage small cutter end effector.
2. Manually control TWRMS (gross positioning).
3. Manually control TWRMS (fine positioning).
4. Monitor end-effector sensor data (visually, haptically, or aurally).
5. Supervise robotic TWRMS and end-effector operations.
6. Manually shut down system–emergency.

2.2.8 Gripper End Effector

The gripper end effector will be used to grasp objects in the tank. It will comprise an end effector attached to the TWRMS.

2.2.8.1 System functions

1. Grasp objects.
2. Provide emergency shutdown.

2.2.8.2 User functions

1. Engage gripper end effector.
2. Manually control TWRMS (gross positioning).
3. Manually control TWRMS (fine positioning).
4. Supervise robotic TWRMS and end-effector operations.
5. Manually shut down system–emergency.

2.2.9 Video Inspection End Effector

The video inspection end effector will comprise a television platform that may be used to perform inspections within the tank. It will likely include a stereo camera pair.

2.2.9.1 System functions

1. Television camera
2. Provide emergency shutdown

2.2.9.2 User functions

1. Manually control TWRMS (gross positioning).
2. Manually control TWRMS (fine positioning).
3. Supervise robotic TWRMS and end-effector operations.
4. Zoom cameras.
5. Iris cameras.
6. Converge cameras.
7. Roll cameras.
8. Manually shut down system–emergency.

2.3 LIFTING LANYARD

The lifting lanyard will be attached to riser pipe and ITH sections to prevent them from falling and to remove them from the tank. It will comprise a lanyard, a clamp or other attachment, and a means for extending or retracting the lanyard. It will be attached to the TWRMS package at the retrieval manipulator lift point.

2.3.1 System Functions

1. Attach large ITH to retrieval manipulator lift point.
2. Provide emergency shutdown.

2.3.2 User Functions

1. Engage lanyard clamp.
2. Manually control TWRMS (gross positioning).
3. Manually control TWRMS (fine positioning).
4. Supervise robotic TWRMS and end-effector operations.
5. Manually shut down system–emergency.

2.4 WASTE CONVEYANCE SYSTEM

The waste conveyance system will remove liquid and particulate waste from the vicinity of the end effector and carry it out of the tank. It will comprise a large hose attached to the TWRMS near the end effector.

2.4.1 System Functions

1. Receive waste from end effectors.
2. Transfer waste to holding receptacle.
3. Monitor waste stream gases.
4. Monitor waste stream radiation.
5. Monitor waste stream flow rate.
6. Provide emergency shutdown.

2.4.2 User Functions

1. Engage waste conveyance system.
2. Visually monitor waste conveyance system.
3. Manually control TWRMS (gross positioning).
4. Manually control TWRMS (fine positioning).
5. Supervise robotic TWRMS and end-effector operations.
6. Visually monitor waste stream gas composition.
7. Monitor waste stream radiation levels (visually or aurally).
8. Monitor waste stream flow rate (visually or aurally).
9. Manually shut down system–emergency.

2.5 ITH CONVEYANCE SYSTEM

The ITH conveyance system will be used to remove riser pipe and ITH sections from the tank. It will comprise a hopper and a means for moving the hopper out of the tank and emptying it.

2.5.1 System Functions

1. Receive ITH from end effectors.
2. Transfer ITH to holding receptacle.
3. Provide emergency shutdown.

2.5.2 User Functions

1. Load ITH holding hopper via manual control of TWRMS (gross and fine positioning).
2. Monitor robotic ITH holding hopper loading.
3. Engage ITH conveyance system.
4. Manually shut down system–emergency.

2.6 CLOSED-CIRCUIT TELEVISION SYSTEM

The closed-circuit television (CCTV) system will be the primary means for providing feedback from the tank. The in-tank portion will comprise several television cameras on pan-tilt mounts attached to the TWRMS.

2.6.1 System Functions

1. Television camera
2. Camera pan, tilt, zoom, and iris
3. End-effector tracking
4. Provide emergency shutdown

2.6.2 User Functions

1. Select camera.
2. Pan camera.
3. Tilt camera.
4. Zoom camera.
5. Iris camera.
6. Roll camera.
7. Engage end-effector tracking.
8. Disengage end-effector tracking.
9. Manually shut down system–emergency.

2.7 AUXILIARY CCTV SYSTEM

The auxiliary CCTV system will supplement the TWRMS CCTV system. It will comprise several television cameras and a camera positioning system.

2.7.1 System Functions

1. During deployment
2. Teleoperated deployment
3. Robotic deployment

2.7.1.1 During operations

1. Television camera.
2. Camera pan, tilt, zoom, and iris.
3. End-effector tracking.
4. Provide emergency shutdown.
5. Teach playback, including teach, step-through playback, semiautomatic playback, and supervised playback.

2.7.2 User Functions

2.7.2.1 During robotic deployment

1. Start system.
2. Initiate robotic deployment sequence.
3. Monitor deployment.
4. Manually shut down system–emergency.
5. Shut down system–normal.
6. Restart system.
7. Maintain operations log.
8. Monitor system status.

2.7.2.2 During teleoperated deployment

1. Start system.
2. Manually maneuver auxiliary television system through opening.
3. Visually monitor deployment.
4. Manually shut down system–emergency.
5. Shut down system–normal.
6. Restart system.
7. Maintain operations log.
8. Monitor system status.
9. Engage teaching.

2.7.2.3 During operations

1. Select camera.
2. Pan camera.
3. Tilt camera.
4. Zoom camera.
5. Iris camera.
6. Roll camera.
7. Engage end-effector tracking.
8. Disengage end-effector tracking.
9. Manually shut down system–emergency.

2.8 SURFACE MAPPING SYSTEM

The surface mapping system will use data collected by in-tank sensors to develop a computer model of the waste surface. The surface map will be used to simulate operations in the tank in real time and can be used to supplement feedback provided by the CCTV systems.

2.8.1 System Functions

1. Acoustic proximity sensor-based surface mapping
2. Optical proximity sensor-based surface mapping
3. Structured light-based surface mapping
4. Laser range finder-based surface mapping
5. Surface mapping integration into world model

2.8.2 User Functions

1. Engage acoustic proximity sensor-based surface mapping.
2. Engage optical proximity sensor-based surface mapping.
3. Engage structured light-based surface mapping.
4. Engage laser range finder-based surface mapping.
5. Monitor mapping progress.

2.9 WHOLE-ARM OBSTACLE AVOIDANCE SYSTEM

The whole-arm obstacle avoidance system will use data generated by sensors in the tank to assist operators in avoiding unwanted collisions with objects in the tank.

2.9.1 System Functions

1. Detect impending collisions.
2. Warn user.
3. Avoid collision by automatically stopping.
4. Avoid collision by automatically indexing.

2.9.2 User Functions

1. Monitor collision avoidance system (visually, haptically, or aurally).
2. Restart system after automatic shutdown.

2.10 MANIPULATOR SENSORS

Sensors integrated into the TWRMS will provide supplementary feedback to the human operators, the surface mapping system, and the whole-arm obstacle avoidance system.

2.10.1 Actuator Position, Velocity, and Torque Sensors

2.10.1.1 System functions

1. Display sensor data (visually, aurally, or haptically).
2. Provide sensor data to control system.

2.10.1.2 User functions

1. Monitor sensor data (visually, haptically, or aurally).

2.10.2 Joint Position, Velocity, and Torque Sensors

2.10.2.1 System functions

1. Display sensor data (visually, aurally, or haptically).
2. Provide sensor data to control system.

2.10.2.2 User functions

1. Monitor sensor data (visually, haptically, or aurally).

2.10.3 Wrist Force-Torque Sensors

1. System functions
2. Display sensor data (visually, aurally, or haptically).
3. Provide sensor data to control system.

2.10.3.1 User functions

1. Monitor sensor data (visually, haptically, or aurally).

2.10.4 Link Accelerometers

2.10.4.1 System functions

1. Display sensor data (visually, aurally, or haptically).
2. Provide sensor data to control system.

2.10.4.2 User functions

1. Monitor sensor data (visually, haptically, or aurally).

2.10.5 Link Strain Gauges

1. System functions
2. Display sensor data (visually, aurally, or haptically).
3. Provide sensor data to control system.

2.10.5.1 User functions

1. Monitor sensor data (visually, haptically, or aurally).

3. OPERATOR CONTROL STATION FUNCTION LIST

Having listed the subsystem functions and operator functions by task phase, the next step is to list only the user functions for each subsystem. This list provides an idea of the scope of user functions and allows formation of an impression of how many functions must be performed at the same time. This section lists the user functions that must be performed for each component of the waste retrieval system.

3.1 TWRMS FUNCTIONS

1. Adjust system parameters (force feedback gain, indexing, and motion gain).
2. Aurally monitor remote sounds.
3. Detect watchdog action.
4. Engage assisted teleoperation.
5. Engage automatic playback.
6. Engage end effector.
7. Engage integrated manipulator control.
8. Engage semiautomatic playback.
9. Engage sensor-based obstacle avoidance.
10. Engage step-through playback.
11. Engage teaching.
12. Initiate automated end-effector changeout.
13. Initiate robotic deployment sequence.
14. Maintain operations log.
15. Manually control end effector using position control (fine positioning).
16. Manually control end effector using position control (gross positioning).
17. Manually control end effector using rate control (fine positioning).
18. Manually control end effector using rate control (gross positioning).
19. Manually make teaching inputs (fine positioning).
20. Manually make teaching inputs (gross positioning).
21. Manually maneuver manipulator through opening.
22. Manually shut down system–emergency.
23. Monitor collision avoidance system.
24. Monitor manipulator forces (visually via displays, haptically via force reflection, or aurally via speakers).
25. Monitor system status.
26. Restart system.
27. Shut down system–normal.
28. Start system.
29. Visually monitor automated end-effector changeout on video.
30. Visually monitor automated end-effector changeout on world model.

31. Visually monitor deployment.
32. Visually monitor end-effector operations on video.
33. Visually monitor end-effector trajectories on video.
34. Visually monitor manipulator position on world model.
35. Visually monitor playback on video.
36. Visually monitor playback on world model.

3.2 SOFT WASTE DISLODGING EQUIPMENT

1. Engage soft waste end effector.
2. Manually control TWRMS (gross positioning).
3. Manually control TWRMS (fine positioning).
4. Manually shut down system–emergency.
5. Monitor end-effector sensor data (visually, haptically, or aurally).
6. Supervise robotic TWRMS and end-effector operations.

3.3 HARD WASTE DISLODGING EQUIPMENT

1. Engage hard waste dislodging end effector.
2. Manually control TWRMS (gross positioning).
3. Manually control TWRMS (fine positioning).
4. Manually shut down system–emergency.
5. Monitor end-effector sensor data (visually, haptically, or aurally).
6. Supervise robotic TWRMS and end-effector operations.

3.4 HARD WASTE RUBBLIZING EQUIPMENT

1. Engage rubblizing end effector.
2. Manually control TWRMS (gross positioning).
3. Manually control TWRMS (fine positioning).
4. Manually shut down system–emergency.
5. Monitor end-effector sensor data (visually, haptically, or aurally).
6. Supervise robotic TWRMS and end-effector operations.

3.5 POST-RUBBLIZING EQUIPMENT

1. Engage post-rubblizing end effector.
2. Manually control TWRMS (gross positioning).
3. Manually control TWRMS (fine positioning).
4. Manually shut down system–emergency.
5. Monitor end-effector sensor data (visually, haptically, or aurally).
6. Supervise robotic TWRMS and end-effector operations.

3.6 IN-TANK CLEANING EQUIPMENT

1. Engage cleaning end effector.
2. Manually control TWRMS (gross positioning).

3. Manually control TWRMS (fine positioning).
4. Manually shut down system–emergency.
5. Monitor end-effector sensor data (visually, haptically, or aurally).
6. Supervise robotic TWRMS and end-effector operations.

3.7 LARGE CUTTER END EFFECTOR

1. Engage large cutter end effector.
2. Manually control TWRMS (gross positioning).
3. Manually control TWRMS (fine positioning).
4. Manually shut down system–emergency.
5. Monitor end-effector sensor data (visually, haptically, or aurally).
6. Supervise robotic TWRMS and end-effector operations.

3.8 SMALL CUTTER END EFFECTOR

1. Engage small cutter end effector.
2. Manually control TWRMS (gross positioning).
3. Manually control TWRMS (fine positioning).
4. Manually shut down system–emergency.
5. Supervise robotic TWRMS and end-effector operations.

3.9 GRIPPER END EFFECTOR

1. Engage gripper end effector.
2. Manually control TWRMS (gross positioning).
3. Manually control TWRMS (fine positioning).
4. Manually shut down system–emergency.
5. Monitor end-effector sensor data (visually, haptically, or aurally).
6. Supervise robotic TWRMS and end-effector operations.

3.10 VIDEO INSPECTION END EFFECTOR

1. Manually control TWRMS (gross positioning).
2. Manually control TWRMS (fine positioning).
3. Manually shut down system–emergency.
4. Supervise robotic TWRMS and end-effector operations.
5. Zoom cameras.
6. Iris cameras.
7. Converge cameras.

3.11 LIFTING LANYARD

1. Engage lanyard clamp.
2. Manually control TWRMS (gross positioning).
3. Manually control TWRMS (fine positioning).
4. Manually shut down system–emergency.
5. Supervise robotic TWRMS and end-effector operation.

3.12 WASTE CONVEYANCE SYSTEM

1. Engage waste conveyance system.
2. Monitor waste conveyance system.
3. Manually control TWRMS (gross positioning).
4. Manually control TWRMS (fine positioning).
5. Manually shut down system–emergency.
6. Supervise robotic TWRMS and end-effector operations.
7. Monitor waste stream gas composition.
8. Monitor waste stream radiation levels (visually or aurally).
9. Monitor waste stream flow rate (visually or aurally).

3.13 ITH CONVEYANCE SYSTEM

1. Engage ITH conveyance system.
2. Load ITH holding hopper via manual control of retrieval arm.
3. Manually shut down system–emergency.
4. Monitor robotic ITH holding hopper loading

3.14 CCTV SYSTEM FUNCTIONS

1. Disengage end effector tracking.
2. Engage end-effector tracking.
3. Iris camera.
4. Manually shut down system–emergency.
5. Pan camera.
6. Select camera.
7. Tilt camera.
8. Zoom camera.

3.15 AUXILIARY CCTV SYSTEM FUNCTIONS

1. Disengage end-effector tracking.
2. Engage end-effector tracking.
3. Engage teaching.
4. Initiate robotic deployment sequence.
5. Iris camera.
6. Maintain operations log.
7. Manually maneuver auxiliary television system through opening.
8. Manually shut down system–emergency.
9. Monitor system status.
10. Pan camera.
11. Restart system.
12. Select camera.
13. Shut down system–normal.
14. Start system.
15. Tilt camera.
16. Visually monitor deployment.
17. Zoom camera.

3.16 SURFACE MAPPING SYSTEM FUNCTIONS

1. Engage acoustic proximity sensor-based surface mapping.
2. Engage laser range finder-based surface mapping.
3. Engage optical proximity sensor-based surface mapping.
4. Engage structured light-based surface mapping.

3.17 WHOLE-ARM OBSTACLE AVOIDANCE SYSTEM FUNCTIONS

1. Monitor collision avoidance system (visually, haptically, or aurally).
2. Restart system after automatic shutdown.

3.18 MANIPULATOR SENSOR FUNCTIONS

3.18.1 Actuator Position, Velocity, and Torque Sensors

1. Monitor sensor data (visually, haptically, or aurally).

3.18.2 Joint Position, Velocity, and Torque Sensors

1. Monitor sensor data (visually, haptically, or aurally).

3.18.3 Wrist Force-Torque Sensors

1. Monitor sensor data (visually, haptically, or aurally).

3.18.4 Link Strain Gauges

1. Monitor sensor data (visually, haptically, or aurally).

4. CREW SIZE AND RESPONSIBILITIES

4.1 CREW SIZE AND FUNCTION ALLOCATION

The function organization provides insights into operations and the number of people required to run the system and allows a preliminary decision about the number of persons that will be required to operate it. Final recommendations will be made after the results of the task analysis currently under way are available. From the function list and what is presently known, it appears that one person could efficiently operate the system; however, a two-person crew would be a safer arrangement. In a two-person scheme, one person would operate the TWRMS, end effector, and subsidiary equipment while the other monitored operations and intervened as necessary to advise, warn, or assist with difficult operations. The following section details the allocation of responsibilities to each crew member; the list is divided into monitoring functions (primarily perceptual) and controlling functions (primarily motor behavior). These functions will map onto displays and controls in the control room.

4.2 TWRMS CHIEF

4.2.1 Monitoring Functions

1. Manipulator/end effector operations
2. Aurally monitor remote sounds.
3. Monitor collision avoidance system (visually, haptically, or aurally).
4. Monitor end effector sensor data (visually, haptically, or aurally).
5. Monitor manipulator forces (visually via displays, haptically via force reflection, or aurally via speakers).
6. Monitor manipulator sensor data (visually, haptically, or aurally).
7. Monitor robotic ITH holding hopper loading.
8. Supervise robotic TWRMS and end-effector operations.
9. Visually monitor automated end-effector changeout on video.
10. Visually monitor automated end-effector changeout on world model.
11. Visually monitor deployment.
12. Visually monitor end-effector operations on video.
13. Visually monitor end-effector trajectories on video.
14. Visually monitor manipulator position on world model.
15. Visually monitor playback on video.
16. Visually monitor playback on world model

4.2.1.1 System Status

1. Detect watchdog action.
2. Monitor system status.
3. Monitor waste conveyance system.

4.2.2 Control Functions

1. Manipulator functions
2. Adjust system parameters (force feedback gain, indexing, and motion gain).
3. Engage assisted teleoperation.
4. Engage automatic playback.
5. Engage semiautomatic playback
6. Engage sensor-based obstacle avoidance.
7. Engage step-through playback.
8. Engage teaching.
9. Initiate automated end-effector changeout.
10. Initiate robotic deployment sequence.
11. Load ITH holding hopper via manual control of TWRMS.
12. Manually control end effector using position control (fine positioning).
13. Manually control end effector using position control (gross positioning).
14. Manually control end effector using rate control (fine positioning).
15. Manually control end effector using rate control (gross positioning).
16. Manually make teaching inputs.
17. Manually maneuver manipulator through opening.
18. Manually shut down system–emergency.
19. Engage integrated manipulator control.

4.2.2.1 End-effector functions

1. Engage end effector.
2. Manually shut down system–emergency.

4.2.2.2 Viewing system functions

1. Converge stereo cameras.
2. Disengage end-effector tracking.
3. Engage end-effector tracking.
4. Engage teaching.
5. Iris camera.
6. Manually maneuver auxiliary television system through opening.
7. Manually shut down system–emergency.
8. Pan camera.
9. Roll camera.
10. Select camera.
11. Tilt camera.
12. Zoom camera.

4.2.2.3 Mapping functions

1. Engage acoustic proximity sensor-based surface mapping.
2. Engage laser range finder-based surface mapping.
3. Engage optical proximity sensor-based surface mapping.
4. Engage structured light-based surface mapping.

4.2.2.4 Other functions

1. Engage ITH conveyance system.
2. Engage lanyard clamp.
3. Engage waste conveyance system.
4. Manually shut down system–emergency.
5. Restart system.
6. Restart system after automatic shutdown.
7. Shut down system–normal.
8. Start system.

4.3 TWRMS MONITOR

4.3.1 Monitoring Functions

1. Manipulator/end-effector operations
2. Aurally monitor remote sounds.
3. Monitor collision avoidance system (visually, haptically, or aurally).
4. Monitor manipulator forces (visually via displays, haptically via force reflection, or aurally via speakers).
5. Monitor robotic ITH holding hopper loading.
6. Monitor end-effector sensor data (visually, haptically, or aurally).
7. Monitor manipulator sensor data (visually, haptically, or aurally).
8. Visually monitor automated end effector changeout on video.
9. Visually monitor automated end-effector changeout on world model.
10. Visually monitor end-effector operations on video.
11. Visually monitor end-effector trajectories on video.
12. Visually monitor deployment.
13. Visually monitor manipulator position on world model.
14. Visually monitor playback on video.
15. Visually monitor playback on world model.

4.3.1.1 System status

1. Monitor system status.

4.3.1.2 Waste Conveyance System

1. Monitor waste conveyance system.
2. Monitor waste stream flow rate (visually or aurally).
3. Monitor waste stream radiation levels (visually or aurally).
4. Visually monitor waste stream gas composition.

4.3.2 Controls

1. Communicate with outside.
2. Maintain operations log.
3. Manually shut down system–emergency.

5. REMAINING PHASES OF THE PROJECT

This section briefly describes the remaining segments of the control room design project.

5.1 TASK ANALYSIS

In the task analysis, the tasks that will be required of operators will be listed, the relationships between tasks will be identified, and procedures for completing tasks will be investigated. This requires listing the tasks and subtasks to be performed, structuring the tasks so that relationships are clearly identified, preparing a dynamic task analysis model, and evaluating options for completing tasks and alternative task procedures.

5.1.1 Identify Tasks

Identifying tasks will proceed alongside function identification and will use some of the same information. However, the task analysis will be more detailed. A task is a set of human actions required to achieve a goal; in effect, the function list provides goals and the task analysis will describe how users will achieve them. Tasks include a stimulus, or cue, that starts the task, a set of task actions (perceptions, discriminations, decisions, control actions, or communications), and a stopping point that provides feedback of results. The outcome of this stage will be a list of tasks performed in the control room during a remediation campaign.

5.1.2 Structure Tasks

Structuring tasks means to organize them in a meaningful fashion, most likely based on the order in which tasks are completed. The outcome of this stage will be a network chart showing how tasks will be carried out.

5.1.3 Prepare Model

During this stage the task structure will be converted into a dynamic, computerized model using the MicroSAINT network modeling package. The outcome of this stage will be a computer simulation of how tasks will be completed, suitable for evaluating work flow and work load in the cockpit.

5.1.4 Evaluate Options/Alternatives

During this stage options for completing tasks and alternative procedures will be evaluated using the model developed in the preceding stage. The outcome of this stage will be a set of recommendations for structuring remediation campaigns to optimize the efficiency of the crew and equipment.

5.2 CONTROL ROOM DESIGN

The third phase of the task will be to develop conceptual designs of control panels, workstations, and the control room layout. In this phase the functional organization developed in the first phase will be translated into recommendations for arranging physical components of the control room. The outcome of this phase will be a set of conceptual design drawings describing workstation and control room layout concepts.

5.2.1 Control Panel Design

Control panels are the building blocks of workstation design and include all displays and controls necessary for one operator to perform an activity for which he is responsible. The outcome of this part of the task will be conceptual designs for all of the control panels required by each crew member.

5.2.2 Workstation Design

Workstations include control panels and supporting equipment. Some crew members may require multiple panels (e.g., a control panel to turn on and initialize the equipment and a control panel to conduct manipulator operations); workstations will be designed to integrate or separate multiple control panels as necessary to optimize user efficiency. Workstations will also support the users by providing room for manuals, storage, etc. The outcome of this part of the task will be conceptual design drawings for workstations, including recommendations for displays, controls, cabinets, and seating.

5.2.3 Control Room Layout

The final stage of the design phase will be to integrate workstations into a control room. The control room layout will optimize cooperation and communication among users of separate workstations. The outcome of this part of the task will be a conceptual design drawing for a recommended layout of workstations within the control room.

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